National Park Service
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Natural Resource Program Center

Understanding the Science of Climate Change

Talking Points: Impacts to the Atlantic Coast

Natural Resource Report NPS/NRPC/NRR—2009/095

ON THE COVER

Assateague Island National Seashore; NPS photo.

Understanding the Science of Climate Change

Talking Points - Impacts to the Atlantic Coast

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Contents

I. Introduction

Purpose

Climate change presents significant risks to our nation's natural and cultural resources. Although climate change was once believed to be a future problem, there is now unequivocal scientific evidence that our planet's climate system is warming (IPCC 2007a). While many people understand that human emissions of greenhouse gases have caused recent observed climate changes, fewer are aware of the specific impacts these changes will bring. This document is part of a series of bio-regional summaries that provide key scientific findings about climate changes in and impacts to protected areas. The information is intended to provide a basic understanding of the science of climate change, known and expected impacts to resources and visitor experience, and actions that can be taken to mitigate and adapt to change. The statements may be used to communicate with managers, frame interpretive programs, and answer general questions to the public and the media. They also provide helpful information to consider in the developing sustainability strategies and long-term management plans.

Audience

The Talking Points documents are primarily intended to provide park and refuge area managers and staff with accessible, up-to-date information about climate change and climate change impacts to the resources they protect.

Organizational Structure

Following the Introduction are three major Sections of the document: a Regional section that provides information on changes to the Atlantic Coast, a section outlining No Regrets Actions that can be taken now to mitigate and adapt to climate changes, and a general section on Global Climate Change. The Regional Section is organized around six types of changes or impacts, while the Global Section is arranged around four topics.

Regional Section

- Temperature
- The Water Cycle (including snow, ice, lake levels, sea level, and ocean acidification)
- Vegetation (plant cover, species range shifts, and phenology)
- Wildlife (aquatic, marine, and terrestrial animals, range shifts, invasive species, migration, and phenology)
- Disturbance (including range shifts, plant cover, plant pests and pathogens, fire, flooding, and erosion)
- Visitor Experience

Global Section

- Temperature and Greenhouse Gases
- Water, Snow, and Ice
- Vegetation and Wildlife
- Disturbance

Information contained in this document is derived from the published results of a range of scientific research including historical data, empirical (observed) evidence, and model projections (which may use observed or theoretical relationships). While all of the statements are informed by science, not all statements carry the same level of confidence or scientific certainty. Identifying uncertainty is an important part of science but can be a major source of confusion for decision makers and the public. In the strictest sense, all scientific results carry some level of uncertainty because the scientific method can only "prove" a hypothesis to be false. However, in a practical world, society routinely elects to make choices and select options for actions that carry an array of uncertain outcomes.

The statements in this document have been organized to help managers and their staffs differentiate among current levels of uncertainty in climate change science. In doing so, the document aims to be consistent with the language and approach taken in the Fourth Assessment on Climate Change reports by the Intergovernmental Panel on Climate Change. However, this document discriminates among only three different levels of uncertainty and does not attempt to ascribe a specific probability to any particular level. These are qualitative rather than quantitative categories and are based on the following:

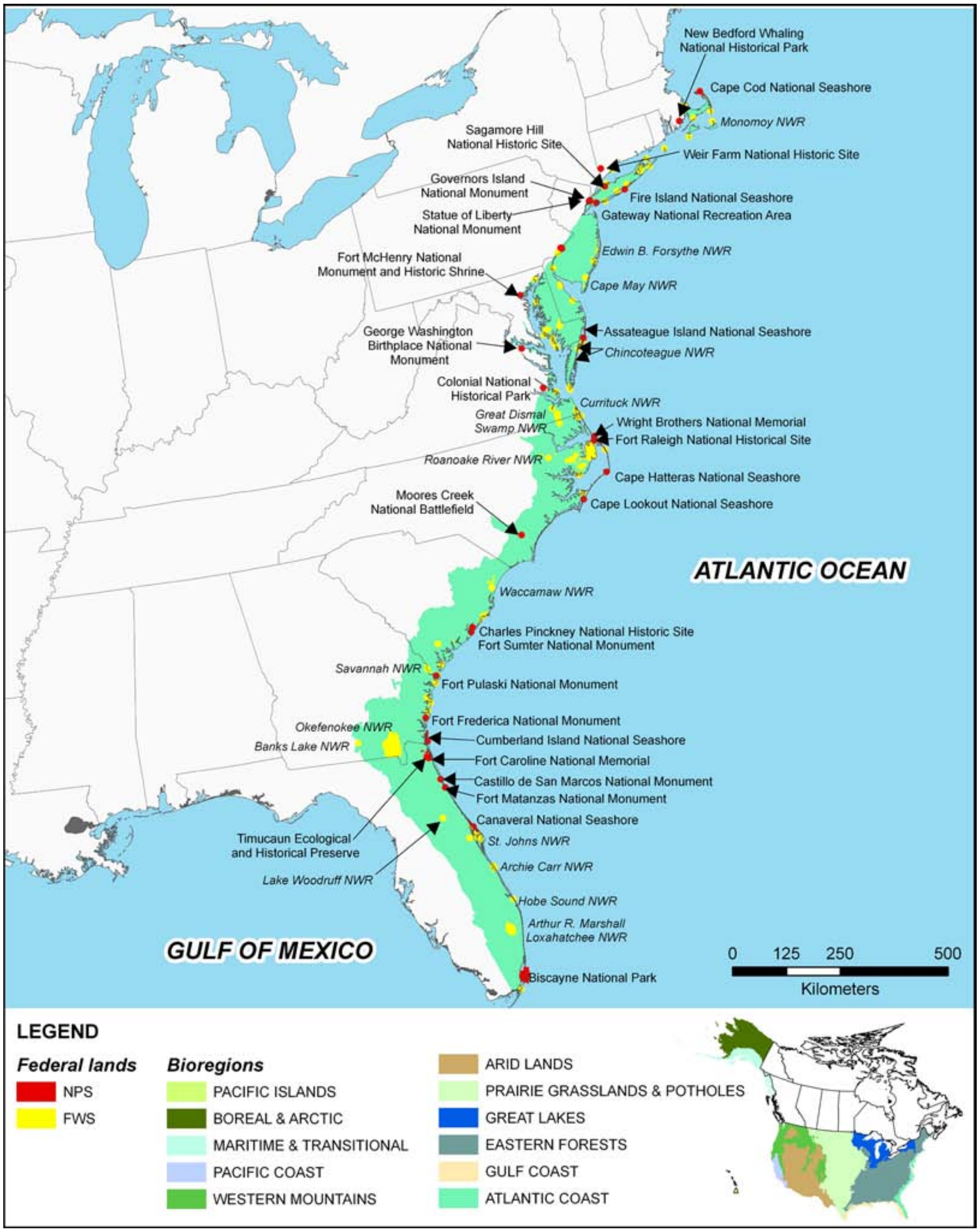
- "What scientists know" are statements based on measurable data and historical records. These are statements for which scientists generally have high confidence and agreement because they are based on actual measurements and observations. Events under this category have already happened or are very likely to happen in the future.

- "What scientists think is likely" represents statements beyond simple facts; these are derived from some level of reasoning or critical thinking. They result from projected trends, well tested climate or ecosystem models, or empirically observed relationships (statistical comparisons using existing data).

- "What scientists think is possible" are statements that use a higher degree of inference or deduction than the previous categories. These are based on research about processes that are less well understood, often involving dynamic interactions among climate and complex ecosystems. However, in some cases, these statements represent potential future conditions of greatest concern, because they may carry the greatest risk to protected area resources.

II. Climate Change Impacts to the Atlantic Coast

The Atlantic Coast bioregion that is discussed in this section is shown in the map to the right. A list of parks and refuges for which this analysis is most useful is included on the next page. To help the reader navigate this section, each category is designated by color-coded tabs on the outside edge of the document.



Summary

Observed 20th century climate changes in the Atlantic Coast bioregion include warmer air and sea surface temperatures, increased winter precipitation (especially rainfall), and an increased frequency of extreme precipitation events. Climate change impacts during the century include phenological shifts in plant and animals species, such as earlier occurrence of lilac budburst and earlier arrival of migrant birds; spread of invasive species such as the Chinese tallow tree; sea level rise; and earlier onset of lake and river ice-out and snowmelt-driven runoff. Climate changes predicted for the region are continued increases in air and sea surface temperatures, a dramatic increase in the summer heat index, increased seasonal precipitation, and more frequent severe thunderstorms. These climate changes are predicted to alter patterns of vegetation distribution (shifting ranges of cool-adapted tree species such as sugar maple and birch), modify coastline ecosystems (inundation of wetlands from sea level rise), reduce available habitat for marine and terrestrial animals, and increase the extent and frequency of coastal flooding and erosion from sea level rise and storm surges.

List of Parks and Refuges

U.S. National Park Service Units

- Assateague Island NS
- Biscayne NP
- Canaveral NS
- Cape Cod NS
- Cape Hatteras NS
- Cape Lookout NS
- Castillo de San Marcos NM
- Castle Clinton NM
- Charles Pinckney NHS
- Colonial NHP
- Cumberland Island NS
- Edgar Allen Poe NHS
- Federal Hall NM
- Fire Island NS
- Fort Caroline NME
- Fort Frederica NM
- Fort Matanzas NM
- Fort McHenry NM & HS
- Fort Pulaski NM
- Fort Raleigh NHS
- Fort Sumter NM
- Gateway NRA
- George Washington Birthplace NM
- Gloria Dei (Old Swedes') Church NHS
- Governor's Island NM
- Independence NHS
- Moores Creek NB
- New Bedford Whaling NHP
- Sagamore Hill NHS
- Statue of Liberty NM
- Thaddeus Kosciuszko NME
- Timucuan Ecological & HP
- Weir Farm NHS
- Wright Brothers NM

U.S. Fish & Wildlife Service Units

- Alligator River NWR
- Amagansett NWR
- Archie Carr NWR
- Arthur R. Marshall Loxahatchee NWR
- Back Bay NWR
- Banks Lake NWR
- Blackbeard Island NWR
- Blackwater NWR
- Block Island NWR
- Bowbay Hook NWR
- Cape May NWR
- Cape Romain NWR
- Cedar Island NWR
- Chincoteague NWR
- Crocodile Lake NWR
- Currituck NWR
- Eastern Neck NWR
- Eastern Shore of Virginia NWR
- Edwin B. Forsythe NWR
- Elizabeth A. Morton NWR
- Ernest F. Hollings Ace Basin NWR
- Fisherman Island NWR
- Franklin Island NWR
- Great Dismal Swamp NWR
- Harris Neck NWR
- Hobe Sound NWR
- John Heinz NWR
- Lake Woodruff NWR
- Lido Beach WMA
- Mackay Island NWR
- Martin NWR
- Mashpee NWR
- Massasoit Neck NWR
- Mattamuskeet NWR
- Merritt Island NWR
- Monomy NWR
- Nansemond NWR
- Nantucket NWR
- Nomans Land Island NWR
- Okefenokee NWR
- Oyster Bay NWR
- Pea Island NWR
- Pelican Island NWR
- Pinckney Island NWR
- Plum Tree Island NWR
- Prime Hook NWR
- Roanoke River NWR
- Savannah NWR
- Seatuck NWR
- St. Johns NWR
- Stewart B. McKinney NWR
- Supawna Meadows NWR
- Susquehanna NWR
- Swanquarter NWR
- Target Rock NWR
- Tybee NWR
- Waccamaw NWR
- Wallops Island NWR
- Wassaw NWR
- Wertmein NWR
- Wolf Island NWR

Acronym	Unit Type
HP	Historic Preserve
HS	Historic Shrine
NB	National Battlefield
NHP	National Historic Park
NHS	National Historic Site
NM	National Monument
NME	National Memorial
NP	National Park
NRA	National Recreation Area
NS	National Seashore
NWR	National Wildlife Refuge

A. Temperature

What scientists know….

- Since 1970 the northeastern region of the U.S. has warmed at a rate of nearly 0.3°C per decade. Winter temperatures have risen even faster, at a rate of 0.7°C per decade from 1970 to 2000 (Frumhoff et al. 2006).

- Data from 73 climate stations in New England and New York show a regional warming of 1.1°C during the 20th century, significantly higher than the observed global temperature increase over the same period (Trombulak and Wolfson 2004).

- There has been an increase in the frequency of extreme-heat days (days where maximum temperatures exceed 50°C) since 1970 (Frumhoff et al. 2006); in addition, nighttime warm temperature extremes have increased faster than daytime temperature extremes, and at a faster rate than observed for other regions of the U.S. (Hayhoe et al. 2007b).

- The largest warming in the southeastern U.S. over the past century has occurred along the Atlantic coast - as much as 2.2°C (NAST 2000).

- Over the past century, regional sea surface temperature (SST) has increased at a rate of 0.5°C per decade in the Gulf of Maine and 0.3°C per decade in the Gulf Stream region (Hayhoe et al. 2007b).

- Recent studies show that the mean temperature of the oceans between depths of 0 and 300 meters increased by 0.31°C between 1948 and 1998 and that this warming signal is observable to depths of 3000 meters (Levitus et al. 2000).

- Water temperatures in the Hudson River increased 0.12°C per decade between 1920 and 1990 (Ashizawa and Cole 1994).

- Temperatures will increase in the Atlantic coast region in the future. The amount of increase will depend upon the amount of greenhouse gases released into the atmosphere and mitigation strategies adopted at regional and global scales (Frumhoff et al. 2006).

What scientists think is likely…

- An increase in annual-mean surface air temperature of 2°C to 3°C is predicted for the eastern continental region (Christensen et al. 2007).

- A doubling of atmospheric CO_2 is projected to result in temperature increases in the southern section of the region of 3.6°C in summer and 4.4°C in fall. In the northern part of the region expected temperature increases range from 4°C in fall to 5°C during the winter season (Moore et al. 1997).

- Average air temperatures in Florida will continue to increase in the coming decades, with average low temperatures in winter increasing by 1.7°C to 5.6°C and average high temperatures in summer increasing by 1.7°C to 3.9°C by 2100 (Harwell et al. 2001).

- Along the Northeast and Southeast coasts, rising temperatures are likely to dramatically increase the heat index in summer, and warmer winters are likely to reduce cold-related stresses. For example, based on present-day average heat index values, by mid-century the state of Massachusetts is projected to resemble New Jersey under a lower emissions scenario, and Maryland under a higher emissions scenario (Frumhoff et al. 2006).

- Some models predict a twofold increase in the number of days that fall above the present-day high-temperature thresholds for warm temperatures, highlighting the potential for changes in mean seasonal temperatures and future shifts in daily temperatures (Hayhoe et al. 2007a).

- Modeled regional sea surface temperatures show an increase of 1.9°C for the Gulf of Maine and 1.2°C for the Gulf Stream region by 2070-2099 (Hayhoe et al. 2007a).

- In confined coastal bays and estuaries, especially along the southern coast, water temperatures will be directly influenced by changes in air temperature. Consequently, the temperatures of these shallow waters are expected to closely track the projections for changes in regional air temperatures, and will be especially vulnerable to increasing warming (Twilley et al. 2001).

What scientists think is possible…

- Modeled projections for the Northeast under high greenhouse gas emissions scenarios show a possible increase in annual average temperatures of 3.6 to 6.9°C (Frumhoff et al. 2006).

- By the late 20th century hot summer conditions may arrive three weeks earlier and last three weeks longer into the fall (Frumhoff et al. 2007).

- The movement of deep water in the Atlantic Ocean through "conveyor belt" circulation could be strongly affected by changes in ocean temperature and salinity (Broecker et al. 1999). Such changes in circulation could reduce the transport of warmer waters from lower latitudes to the North Atlantic region and lead to a general cooling trend throughout the area; however, there is no evidence to date that the ocean's heat-laden conveyor is slowing (Kerr 2006).

B. The Water Cycle

What scientists know….

- In the Northeast winter precipitation (both rain and snow) increased during the last few decades of the 20th century. Because of rising winter temperatures more winter precipitation is falling as rain rather than snow (Frumhoff et al. 2006).

- The Northeast has experienced an increase in extreme precipitation events (those that result in accumulation of > 5 cm of rainfall) since the early 1900's (Wake 2005).

- Records indicate both an average decrease in the amount of snow over most of New England from 1949 to 2000, as well as an average decrease in the ratio of snow to total precipitation recorded in much of the region. Most records in the region have shown decreases in snowpack depth from the 1950s through 2004 (Wake 2005, Hodgkins and Dudley 2006).

- Hydrologic indicators of 20th century warming trends include earlier onset of lake ice-out, river ice-out, and snowmelt-driven spring runoff (Wake 2005, Frumhoff et al. 2006, Hodgkins and Dudley 2006).

What scientists think is likely….

- In the Northeast winter precipitation is projected to increase throughout the 21st century. Little change is expected in summer rainfall, although projections are highly variable (Frumhoff et al. 2006).

- Future changes in precipitation will affect the total amount of water available water in streams, lakes, and stored groundwater. Timing of peak flow and low flows, and timing and magnitude of extreme events will be affected (Hayhoe et al. 2007a).

- Wetter winters and warmer temperatures in the Northeast will likely drive increases in winter runoff, decreases in spring runoff, and increases in annual runoff as peak runoff shifts to earlier in the year (Hayhoe et al. 2007a).

- Warmer temperatures will result in an increase in evaporation. The bulk of increased evaporation is projected to occur during the spring and summer, and could significantly impact the vulnerability of the region to drought during these times (IPCC 2007a).

Icy waters at Acadia National Park; NPS photo.

Threatened Seabeach Amaranth, native to barrier island beaches; USFWS photo.

- Most model simulations suggest a steady increase in annual precipitation with a total increase of 10%, or about 10 cm per year, by the end of the 21st century (Frumhoff et al. 2006).

- A recent study predicted a net increase during the late 21st century in the number of days in which severe thunderstorm environmental conditions (NDSEV) occur. The largest increases in NDSEV are during the summer season, in proximity to the Gulf of Mexico and Atlantic coastal regions (Trapp et al. 2007).

- Predicted increases in storm intensity and clustering may result in higher peak stream flows, lower base flows, and longer periods of drought (Mulholland et al. 1997).

What scientists think is possible….

- The length of the winter snow season could be reduced by half across northern New York, Vermont, New Hampshire, and Maine, and limited in duration to a week or two in the southern part of the region (Frumhoff et al. 2007).

- Warmer temperatures will cause an increase in evaporation. The bulk of increased evaporation is projected to occur during the spring and summer, and could significantly impact the region's vulnerability to drought (Frumhoff et al. 2006).

- Rising temperatures are projected to increase evaporation across the Northeast. Most increases are projected to occur in the spring and summer and appear to be primarily driven by increasing temperatures and available soil moisture from increased precipitation. These changes have important implications for future water availability and drought in the region (Hayhoe et al. 2007a).

C. Vegetation

What scientists know….

- Changes in climate significantly affect vegetation phenology, morphology, distribution, growth, and reproduction. Most observed changes are linked with temperature change either directly or indirectly (e.g. altered moisture availability) (Root et al. 2003).

- Although it has been widely observed that enrichment of atmospheric CO_2 has a fertilizing effect on most herbaceous and woody plants through enhanced photosynthesis and water-use efficiency, growth and productivity are ultimately limited by factors such as availability of soil water and nutrients (Burkett et al. 2005).

- In wild plants and animals, climate-induced extinctions, distributional and phenological changes, and species range shifts are being documented at a growing rate (Parmesan 2006).

- Many plant species have experienced a shift in the timing of phenological events such as blooming, in response to seasonal changes linked to climate change. For example, lilac budburst has occurred on average 3 days earlier for every 1°C increase in spring temperature (Hughes 2000, Marra et al. 2005).

- The spread of invasive species has been on the rise over the past 50 years due to a number of factors including climatic conditions. For example, the Chinese tallow tree has been invading coastal prairies from the Carolinas to south Texas, where periods of flooding have decreased (Twilley et al. 2001).

- Harmful algal blooms (red tides) have become more extensive in recent years. Warmer coastal waters, especially in combination with nutrient pollution, can increase the intensity, duration, and extent of blooms of harmful algae and cyanobacteria (Harvell et al. 1999).

- Mangrove systems and other tidal wetlands are threatened by climate change impacts, especially sea-level rise. Other climate change impacts that threaten these ecosystems include high water events, storm surges, and ocean circulation patterns. Loss of mangroves will result in reduced coastal water quality, reduced biodiversity, loss of fish and crustacean nursery habitat, and loss of ecosystem services for human populations (Gilman et al. 2008).

- Insects and pathogens that affect vegetation have shorter life spans than most forest vegetation, and can therefore respond more rapidly to climate change (Epstein 2001, Harvell et al. 2002). Climate change can alter both the timing of development and the phenology of insect pests, causing increases in virulence, changes in range, and increases in the spread of diseases (Lovett et al. 2006).

What scientists think is likely….

- Dramatic increases in Southern red cedar and palmetto palm mortality observed during 2000-2005 are likely due to the combined effects of a major drought and ongoing sea level rise (Desantis et al. 2007).

- As the result of increased springtime temperatures some trees and other plant species may come out of dormancy early, making them more vulnerable to late season cold temperature events (Walther et al. 2002).

- Climate changes will likely reduce the regional distributions of cool adapted tree species such as sugar maple and birch, and shift thzeir ranges further north into Canada. Oaks, hickories, and pines may see an expansion of potential habitats, although expansion may be limited by soil types and seed dispersal (Watson 1996, Parmesan 2006).

- Plant-animal interactions such as pollination, seed dispersal, and insect control depend on synchrony between species. Although some species may respond to climate change at similar rates and maintain synchrony, for other species the loss of synchrony (such as mismatched timing between larval emergence and growth of host plants) may have detrimental effects (Burkett et al. 2005)

- Invasive species are likely to expand their ranges northward due to shifts in temperature and precipitation patterns. Invasions may result in altered species compositions, ecosystem function, and native population declines or extinctions (McCarty 2001).

- Salt marshes may be able to survive rates of sea-level rise as high as 50 centimeters in 50 years, an estimate that is lower than the expected rise in sea level for much of the coastal U.S. over the next 100 years. Local subsidence or hydrologic changes, however, could increase the rate of relative sea level rise experienced by individual marshes, potentially exceeding the local threshold of some salt marshes to adapt (Boesch et al. 2000).

- In general, coastal wetlands will survive if increase in sediment surface elevation equals the rate of relative sea level rise or if they are able to migrate inland or to areas of higher elevation. However, if soil accumulation does not keep pace with sea level rise, or if bluffs, coastal development, or shoreline protective structures (e.g. dikes, sea walls, and jetties) block wetland migration, wetlands may be excessively inundated or reduced in area (Scavia et al. 2002, Gilman et al. 2008).

- Freshwater and brackish wetlands, common to the mid- and south Atlantic coasts, are particularly sensitive to sustained or pulsed salinity penetration; such pulses are expected to increase in magnitude and frequency with climate change and will likely result in a transition to more salt tolerant species (Boesch et al. 2000).

Girl observes mangroves at Biscayne National Park (Top); Mangroves at Everglades National Park (Bottom); NPS photos.

Beach at Assateague Island National Seashore (Top); NPS photo. Fire at Prime Hook National Wildlife Refuge (Bottom); USFWS photo.

- Higher river flows result in increased transportation of suspended sediments to coastal waters, increasing the upper layer turbidity and also potentially reducing available light for submerged aquatic vegetation. This may reduce or hinder growth and survival of seagrasses (Boesch et al. 2000).

What scientists think is possible….

- Forest fire seasonal severity rating is projected to increase from 10 to 30% in the Southeast and 10 to 20% in the Northeast by 2060. In addition, model projections simulate a large increase in fire activity and biomass loss in the Southeast, sufficient to convert the southernmost closed-canopy forests to savannas (Backlund et al. 2008).

- A case study for Delaware suggests that by the end of the 21st century 1.6% of its land area and 21% of its wetlands will be lost to an encroaching ocean. Warming will result in the northward displacements of some mobile estuarine species and will exacerbate the already low summer oxygen levels in mid-Atlantic estuaries because of increased oxygen demand and decreased oxygen solubility. Streamflow increases could substantially degrade water quality, with significant negative consequences for submerged aquatic vegetation and birds (Najjar et al. 2000).

- Climate changes may reduce the extent of northern hardwood forests (forests currently cover 65% of the mid-Atlantic landscape), resulting in the emergence of a different and possibly less diverse community of tree species (Fisher et al. 2000).

- Warmer winter temperatures projected for the southeastern U.S. may make possible the northward expansion of mangroves possible (Boesch et al. 2000).

D. Wildlife

What scientists know….

- In a study of the first arrival dates of migrant birds in the northeast, all 103 species in the study arrived significantly earlier as compared to previous decades. Birds wintering in the southeastern U.S. arrived on average 13 days earlier (Backlund et al. 2008).

- Behavioral and genetic responses to climate change have been documented across multiple studies in marine, freshwater, and terrestrial ecosystems, in both plant and animal communities (Parmesan 2006).

- Studies have found an advance of 10–13 days in first date of spring mating calls for frog species in upstate New York since the beginning of the century (Gibbs and Breisch 2001). Advances in the timing of migration of anadromous fish (Atlantic salmon and alewives) in New England rivers during the last few decades have also been reported (Huntington et al. 2003, Juanes et al. 2004).

Great Egret at Cape Hatteras National Seashore (Top); American Crocodile at Everglades National Park (Bottom); NPS photos.

- Birds have exhibited a variety of responses to warming trends including earlier breeding dates, range expansions, and asynchronous life history events (Marra et al. 2005).

- Egg-laying for many North American bird species has moved to an earlier calendar date over the last fifty years. The egg-laying date in tree swallows in North America advanced by as many as nine days between 1959 and 1991 (Dunn and Winkler 1999).

- Mass mortalities resulting from disease outbreaks have recently affected major taxa in the oceans. For example, in response to above-average winter temperatures the oyster parasite *Perkinsus marinus* extended its range 500 kilometers northward in a single year, from Chesapeake Bay to Maine (Parmesan 2006).

- In very shallow water such as bays, lagoons, or reservoirs high surface temperatures can lead to hypoxia or anoxia (low dissolved oxygen conditions), causing massive die-offs of fish and invertebrate species. For example, extensive hypoxia that occurred in Chesapeake Bay in 2003 and 2005 is attributed to a combination of high river inflows, warm temperatures, and relatively calm summer winds (Ebi et al. 2007).

What scientists think is likely….

- Changes in terrestrial and aquatic species compositions are likely to occur as ranges shift, contract, or expand. Rare species and communities may disappear, and more common species may become rare (Burns et al. 2003). Range-restricted species (such as those at high elevations) and endemics will likely be the first to experience severe range contraction and extinction due to climate change (Parmesan 2006).

- Sea-level rise could reduce essential habitat for many important marine species, such as shrimp, crabs, and smaller fish; many of these species provide an important forage base for other fishes, marine mammals, and sea birds and may therefore cause significant disturbance across taxa and throughout food webs (Scavia et al. 2002).

- Hypoxic conditions in Chesapeake Bay are projected to increase with warming temperatures, because higher temperatures reduce the amount of oxygen that can be dissolved in water and reduce mixing of the water column. Hypoxia may significantly impair ecosystem functions in the bay through changes in nutrient cycling, altered interactions between predators and prey, changes in food web structure (e.g. loss of zooplankton and benthic organisms), and altered species migration routes and distributions (Ebi et al. 2007).

- More frequent and/or extended periods of low streamflow below critical thresholds will be more likely in the future and will adversely affect stream habitat for fish and other aquatic species in the region (Hayhoe et al. 2007a).

- Changes in water quality under climate change will indirectly affect bird species, primarily through changes in the distribution and abundance of food resources and the loss of nesting and foraging habitat (Najjar et al. 2000).

- Large changes in bird communities of the Northeast are likely to result from temperature changes. High-elevation bird species may currently be at the threshold of critical change, and as little as 1 °C of warming may reduce suitable habitat by more than half. Similarly, mid-elevation species are likely to experience declines in habitat quality that could affect demography. Affected species include the common loon and black-capped chickadee (Rodenhouse et al. 2008).

Loggerhead Sea Turtle hatchling (Top); USFWS photo. Spiny lobster at Biscayne National Park (Bottom); NPS photo.

- Higher air temperatures may result in a shift in sex ratio of sea turtles, with more female offspring produced at higher temperatures (Booth 2006, Hawkes et al. 2007). Populations of turtles in southern parts of the United States are currently highly female biased and are likely to become ultra-biased with as little as 1ºC of warming, and experience extreme levels of mortality if warming exceeds 3ºC. For example, at modeled temperature increases of 7.5ºC, loggerhead turtles show 100% female hatchling production and lethally high incubation (Hawkes et al. 2007).

What scientists think is possible….

- Specific changes in mammal populations and movements may be hard to predict due to the complexity of interactions with their environment and the rapid pace of change that is expected. U.S. national parks could lose on average 8.3% and up to 20% of current mammalian species diversity. The greatest loss of species (>20%) is expected to occur in the most southerly national parks where ecosystem types will become more limited (Burns et al. 2003).
- Because different species are likely to respond differently to climate change, current ecological communities may ultimately be replaced by entirely new assemblages of species (Root et al. 2003).
- Warming temperatures may drive complex shifts in ocean circulation, nutrient supplies, plankton production, and other factors that shape marine ecosystems, in ways that are difficult to predict (Frumhoff et al. 2007).
- Both climate and human activities may accelerate global transport of species, bringing together pathogens and previously unexposed host populations. Adding to their susceptibility, climate-mediated, physiological stresses may compromise host resistance and increase frequency of opportunistic diseases (Harvell et al. 1999).
- Because cold-water fish have high sensitivity to thermal stress, habitat for these species (such as trout and salmon) could be reduced by 30-60% by 2100 (Preston 2006).
- There is particular concern for individual animal species that are already stressed and have greatly reduced ranges, such as the manatee, Cape Sable sparrow and Florida panther. Additional stress resulting from higher temperatures could put those populations at increased risk for extirpation or extinction (Harris and Cropper 1992).

E. Disturbance

What scientists know….

- The two major causes of sea level rise are thermal expansion of the oceans and loss of land-based ice (continental ice sheets and glaciers) due to melting. Global average sea level rose at an average rate of 1.8 mm per year from 1961 to 2003 and at an average rate of 3.1 mm per year from 1993 to 2003 (IPCC 2007c).

Damage from Hurricane Ivan at Delaware Water Gap National Recreation Area; NPS photos.

- Sea level rise observed along U.S. coastlines varied between and within regions during the 1900s, but in general the U.S. Gulf of Mexico and South Atlantic coasts (with the exception of Florida) have experienced rates of relative sea level increase that are significantly greater than those observed on the U.S. Pacific coast or farther north on the Atlantic Coast (Scavia et al. 2002).

- Local rates of relative sea level rise (local net increase in sea level due to changes in both global average sea level and local land movement) vary from about 2 mm year in New England and Florida to 3-5 mm year in the mid-Atlantic. Relative sea level in the Northeast has risen an average of about 25 cm since 1920 (Nicholls and Leatherman 1996, Zervas 2004).

- Coastal vulnerability is influenced by the relative resistance of a shoreline to erosion, and its susceptibility to inundation and flooding. Over 27% of the U.S. Atlantic coastline has been assessed to have a "very high" vulnerability to sea level rise, and a further 22% has a "high" vulnerability rating (Thieler and Hammar-Klose 1999). Coastal impacts of sea-level rise may include shoreline erosion, saltwater intrusion into groundwater aquifers, inundation of wetlands and estuaries, and threats to cultural and historic resources and infrastructure (Pendleton et al. 2004)

- An estimated 2,000 km^2 of land in the Northeast is less than 1.5 meters above the present sea level (Wake 2005). North Carolina has the third largest area of land close to sea level, following Louisiana and Florida, and as such is very vulnerable to sea level rise and its effects (Titus and Richman 2001).

- The coastal areas that are most vulnerable to future increases in sea level are those with low relief and those that are already experiencing rapid erosion rates. Most of the Atlantic shoreline is moderately to severely eroding, increasing its susceptibility to change due to sea level rise (NAST 2000).

- Atlantic tropical cyclone (hurricane) activity, as measured by both frequency and the Power Dissipation Index (which combines storm intensity, duration, and frequency) has increased. The increases are substantial since about 1970, in association with warming Atlantic sea surface temperatures (Kunkel et al. 2008).

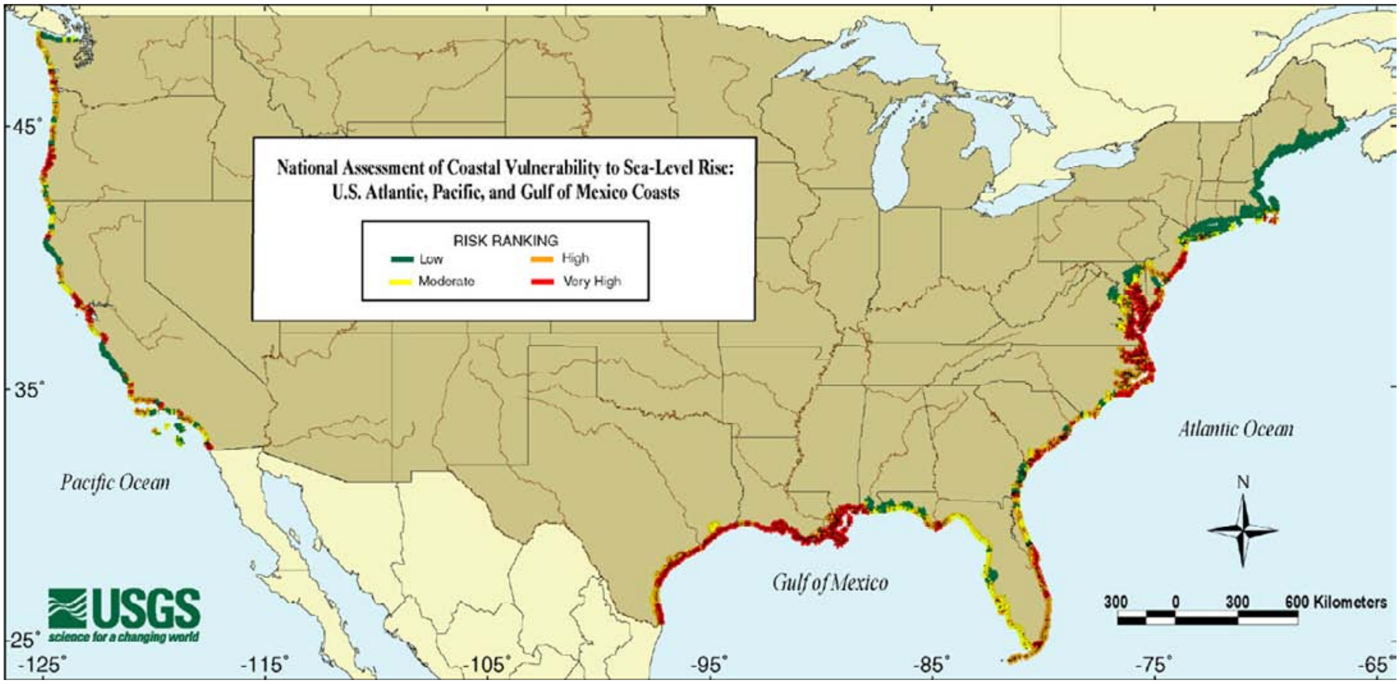
- Storms, hurricanes, and typhoons produce high winds which in turn generate large waves and currents. The storms may also produce storm surges that temporarily raise water levels far above normal. For example, in 1969 Hurricane Camille, a Category 5 hurricane, induced a 7 meter storm surge along the Mississippi coast. These surges are a primary cause of beach erosion in the U.S., and usually move nearshore and beach sand seaward, where it may be stored in offshore bars or lost from the active system (Boesch et al. 2000).

What scientists think is likely….

- Even if greenhouse gas emissions are stabilized, the rate of sea level rise will likely continue to increase beyond 2100 because of the time it takes for oceans and ice sheets to approach equilibrium conditions with the atmosphere (Scavia et al. 2002).

- Sea level rise is projected to permanently inundate low-lying coastal areas and increase shoreline erosion and wetland loss. The areas most vulnerable to shoreline erosion include portions of Cape Cod, Long Island, and most of coastal New Jersey (Frumhoff et al. 2007).

- Many areas of the densely populated Northeast coast face substantial increases in the extent and frequency of coastal flooding and are at increased risk of severe storm-related damage. Boston and Atlantic City, for example, can expect a coastal flood equivalent to today's 100-year flood every two to four years on average by the mid-21st century, and almost annually by the end of the century (Frumhoff et al. 2007).



Coastal vulnerability in the U.S. is most pronounced along the gulf and Atlantic coasts; USGS image.

- Increases in sea surface temperature are causally linked to increased hurricane frequency, suggesting that as warming continues increases in the strength and duration of tropical storms are likely; these storms pose significant risks for coastal communities and ecosystems (Frumhoff et al. 2006).

- A rise in sea level or changes in storms or storm surges will result in the increased erosion of shores and associated habitat, altered tidal ranges in rivers and bays, increased salinity of estuaries and freshwater aquifers, changes in patterns of chemical and microbiological contamination in coastal areas, and a change in sediment and nutrient transport and increased coastal flooding. Secondary impacts associated with sea-level rise include inundation of waste disposal sites and landfills and the subsequent release of toxins and pollutants; and increased siltation of subtidal habitats due to shoreline erosion (Boesch et al. 2000).

What scientists think is possible….

- Model-based projections of global average sea level rise at the end of the 21st century range from 0.18 to 0.59 meters, depending on specific emissions scenarios (IPCC 2007b). These estimates are conservative because they do not account for the rapid rate of decay and melting of the major polar ice sheets currently being observed (especially in Greenland), nor do they incorporate the potential for further acceleration of this melting (Frumhoff et al. 2007).

- Some climate experts believe with near certainty that current climate trends will lead to a multi-meter sea level rise by 2100 if emissions of CO_2 and other greenhouse gases continue to increase (Hansen 2007).

- Sea level rise and its secondary effects may dramatically alter landscapes, and reduce habitat quality for wildlife species. Changes in the frequency of severe storms and increased rainfall intensity could further aggravate flooding and storm damage (Titus and Richman 2001).

- Decreased runoff coupled with increasing sea levels could lead to increased salt-water intrusion in some areas, affecting vegetation, fish, and water resources (Twilley et al. 2001, IPCC 2007a).

- Projections for mid-century changes in coastal flooding include increases in the maximum elevation of major coastal floods and increased frequency of 100-year flood events. For example, 100-year floods are expected at Woods Hole, MA every 46 to 50 years, depending on emissions scenario, and every two the thee years in Boston (Frumhoff et al. 2007).

Temperature
Water Cycle
Vegetation
Wildlife
Disturbance
Visitor Experience

Visitors enjoying a bike ride in Assateague Island National Seashore; NPS photo.

F. Visitor Experience

- Changes to the terrestrial and aquatic species compositions in parks and refuges are likely to occur as ranges shift, contract, or expand. Rare species and/or communities may become further at risk, and additional species could become rare (Burns et al. 2003).

- Parks and refuges may not be able to meet their mandate of protecting current species within their boundaries, or in the case of some refuges, the species for whose habitat protection they were designed. While wildlife may be able to move northward or to higher elevations to escape some effects of climate change, federal boundaries are static (Burns et al. 2003).

- Changes in wildlife composition will impact activities such as fishing and bird watching in parks and refuges.

- Peak tourism times may change as temperature and precipitation patterns change. For example, earlier onset of the spring season and later onset of fall will likely affect timing of visitations.

- The winter recreation season is likely to become shorter and less reliable in the future. For example, the length of the winter snow season could be cut in half across northern New York, Vermont, New Hampshire, and Maine, and reduced to a week or two in southern parts of the region (Frumhoff et al. 2007)

- Increased temperatures and CO_2 levels may worsen pollen-based allergies. Heat-related illness may also increase with an increase in the number of extremely hot days, and increased ozone and airborne pollutants (including dust and smoke) may exacerbate the risk of respiratory, cardiovascular, and other diseases. In addition, hotter, longer, drier summers punctuated by heavy rainstorms may create favorable conditions for more frequent outbreaks of mosquito-borne diseases such as West Nile virus (Frumhoff et al. 2007).

- Visitor facilities may need to be upgraded to ensure continued quality of visitor experience under more extreme conditions, and structures threatened by storm surges or rising sea levels may need to be moved or protected.

- Visitor access to certain areas may be restricted to provide for climate change refugia or reduce stress on certain areas or species.

- Increased summer temperatures will lead to increased utility expenditures in parks in the summer and, potentially, decreases in the winter.

- Under a high emissions scenario only the northern New England states and the North Country of New York are projected to support viable ski operations by the middle of the 21st century. By the latter part of the century, only western Maine is projected to retain a reliable ski season under a high emissions scenario (Burns et al. 2003, Frumhoff et al. 2007).

- Visitor season may be extended for many of the more northern parks and refuges due to lengthening of the frost-free season, and visitor use during the summer will likely decrease in some southern parks and refuges due to higher temperatures during this time.

- Disturbance events such as forest fires, droughts, storms, and floods may become more common, stressing natural environments and impacting park infrastructure and visitor experiences.

- Seal level rise and storm damage may result in loss of access to and accelerated deterioration of cultural resources along the coast.

- Milder winters along the Atlantic Coast could contribute to higher survival rates for mice and deer. As hosts for deer ticks, the primary vector for Lyme disease, increased survival of these species could impact the rate of infection in humans (Patz et al. 2000).

- Increased temperatures and earlier springs may increase the number and size of breeding grounds available for mosquitoes, increasing transmission risk of mosquito-borne diseases such as dengue and yellow fever likely to increase (Patz et al. 2000).

- Increasing frequency and intensity of severe storms and floods may pose threats to historic structures, roads and trails, archeological sites, administrative facilities, and other park resources and infrastructure.

Children visiting Everglades National Park; NPS photo.

III. No Regrets Actions: How Individuals, Parks, Refuges, and Their Partners Can Do Their Part

Individuals, businesses, and agencies release carbon dioxide (CO_2), the principal greenhouse gas, through burning of fossil fuels for electricity, heating, transportation, food production, and other day-to-day activities. Increasing levels of atmospheric CO_2 have measurably increased global average temperatures, and are projected to cause further changes in global climate, with severe negative implications for vegetation, wildlife, oceans, water resources, and human populations. Emissions reduction – limiting production of CO_2 and other greenhouse gases - is an important step in addressing climate change. It is the responsibility of agencies and individuals to find ways to reduce greenhouse gas emissions and to educate about the causes and consequences of climate change, and ways in which we can reduce our impacts on natural resources. There are many simple actions that each of us can take to reduce our daily carbon emissions, some of which will even save money.

Agencies Can...

Improve sustainability and energy efficiency

- Use energy efficient products, such as ENERGY STAR® approved office equipment and light bulbs.
- Initiate an energy efficiency program to monitor energy use in buildings. Provide guidelines for reducing energy consumption.
- Convert to renewable energy sources such as solar or wind generated power.
- Specify "green" designs for construction of new or remodeled buildings.
- Include discussions of climate change in the park Environmental Management System.
- Establish an in-park sustainability team and develop sustainability Best Management Practices. Request and hold Climate Friendly Park workshops in cooperation with the EPA.
- Provide alternative transportation options such as employee bicycles and shuttles for within-park commuting.
- Provide hybrid electric or propane-fueled vehicles for official use, and impose fuel standards for park vehicles. Reduce the number and/or size of park vehicles and boats to maximize efficiency.
- Provide a shuttle service or another form of alternate transportation for visitor travel to and within the park.
- Provide incentives for use of alternative transportation methods.
- Use teleconferences or other forms of modern technology in place of travel to conferences and meetings.

Management Actions

- Engage and enlist collaborator support (e.g., tribes, nearby agencies, private landholders) in climate change discussions, responses, and mitigation.
- Develop strategies and identify priorities for managing uncertainty surrounding climate change effects in parks and refuges.
- Build a strong partnership-based foundation for future conservation efforts.
- Identify strategic priorities for climate change efforts when working with partners.
- Incorporate anticipated climate change impacts, such as decreases in lake levels or changes in vegetation and wildlife, into management plans.

An interpretive brochure about climate change impacts to National Parks was created in 2006 and was distributed widely.

Park Service employees install solar panels at San Francisco Maritime National Historical Park (Top); At the National Mall, Park Service employees use clean-energy transportation to lead tours; NPS photos.

- Encourage research and scientific study in park units and refuges.
- Design long-term monitoring projects and management activities that do not rely solely on fossil fuel-based transportation and infrastructure.
- Incorporate products and services that address climate change in the development of all interpretive and management plans.
- Take inventory of the facilities/boundaries/species within your park or refuge that may benefit from climate change mitigation or adaptation activities.
- Participate in gateway community sustainability efforts.
- Recognize the value of ecosystem services that an area can provide, and manage the area to sustain these services. Conservation is more cost-effective than restoration and helps maintain ecosystem integrity.
- Provide recycling options for solid waste and trash generated within the park.

Restore damaged landscapes

- Restoration efforts are important as a means for enhancing species' ability to cope with stresses and adapt to climatic and environmental changes. Through restoration of natural areas, we can lessen climate change impacts on species and their habitats. These efforts will help preserve biodiversity, natural resources, and recreational opportunities.
- Strategically focus restoration efforts, both in terms of the types of restoration undertaken and their national, regional, and local scale and focus, to help maximize resources.
- Restore and conserve connectivity within habitats, protect and enhance instream flows for fish, and maintain and develop access corridors to climate change refugia.
- Restore natural hydrologic functions of coastal wetlands to help protect coastal areas against hurricanes and flooding.

Educate staff and the public

- Post climate change information in easily accessible locations such as on bulletin boards and websites.
- Provide training for park and refuge employees and partners on effects of climate change on resources, and on dissemination of climate change knowledge to the public.
- Support the development of region, park, or refuge-specific interpretive products on the impacts of climate change.
- Incorporate climate change research and information in interpretive and education outreach programming.
- Distribute up-to-date interpretive products (e.g., the National Park Service-wide Climate Change in National Parks brochure)
- Develop climate change presentations for local civic organizations, user and partner conferences, national meetings, etc..
- Incorporate climate change questions and answers into park-based Junior Ranger programs.
- Help visitors make the connection between reducing greenhouse gas emissions and resource stewardship.

"Humankind has not woven the web of life. We are but one thread within it. Whatever we do to the web, we do to ourselves. All things are bound together. All things connect."
—Chief Seattle

- Encourage visitors to use public or non-motorized transportation to and around parks.

- Encourage visitors to reduce their carbon footprint in their daily lives and as part of their tourism experience.

Individuals can...

- In the park or refuge park your car and walk or bike. Use shuttles where available. Recycle and use refillable water bottles. Stay on marked trails to help further ecosystem restoration efforts.

- At home, walk, carpool, bike or use public transportation. A full bus equates to 40 fewer cars on the road. When driving, use a fuel-efficient vehicle.

- Do not let cars idle - letting a car idle for just 20 seconds burns more gasoline than turning it off and on again.

- Replace incandescent bulbs in the five most frequently used light fixtures in the home with bulbs that have the ENERGY STAR® rating. If every household in the U.S. takes this one simple action we will prevent greenhouse gas emissions equivalent to the emissions from nearly 10 million cars, in addition to saving money on energy costs.

Reduce, Reuse, Recycle, Refuse

- Use products made from recycled paper, plastics and aluminum - these use 55-95% less energy than products made from scratch.

- Purchase a travel coffee mug and a reusable water bottle to reduce use of disposable products (Starbucks uses more than 1 billion paper cups a year).

- Carry reusable bags instead of using paper or plastic bags.

- Recycle drink containers, paper, newspapers, electronics, and other materials. Bring recyclables home for proper disposal when recycle bins are not available. Rather than taking old furniture and clothes to the dump, consider "recycling" them at a thrift store.

- Keep an energy efficient home. Purchase ENERGY STAR® appliances, properly insulate windows, doors and attics, and lower the thermostat in the winter and raise it in the summer (even 1-2 degrees makes a big difference). Switch to green power generated from renewable energy sources such as wind, solar, or geothermal.

- Buy local goods and services that minimize emissions associated with transportation.

- Encourage others to participate in the actions listed above.

For more information on how you can reduce carbon emissions and engage in climate-friendly activities, check out these websites:

EPA- What you can do: http://www.epa.gov/climatechange/wycd/index.html

NPS- Do Your Part! Program: http://www.nps.gov/climatefriendlyparks/doyourpart.html

US Forest Service Climate Change Program: http://www.fs.fed.us/climatechange/

United States Global Change Research Program: http://www.globalchange.gov/

U.S. Fish and Wildlife Service Climate change: http://www.fws.gov/home/climatechange/

The Climate Friendly Parks Program is a joint partnership between the U.S. Environmental Protection Agency and the National Park Service. Climate Friendly Parks from around the country are leading the way in the effort to protect our parks' natural and cultural resources and ensure their preservation for future generations; NPS image.

IV. Global Climate Change

The IPCC is a scientific intergovernmental, international body established by the World Meteorological Organization (WMO) and by the United Nations Environment Programme (UNEP). The information the IPCC provides in its reports is based on scientific evidence and reflects existing consensus viewpoints within the scientific community. The comprehensiveness of the scientific content is achieved through contributions from experts in all regions of the world and all relevant disciplines including, where appropriately documented, industry literature and traditional practices, and a two stage review process by experts and governments.

Definition of climate change: The IPCC defines climate change as a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer.

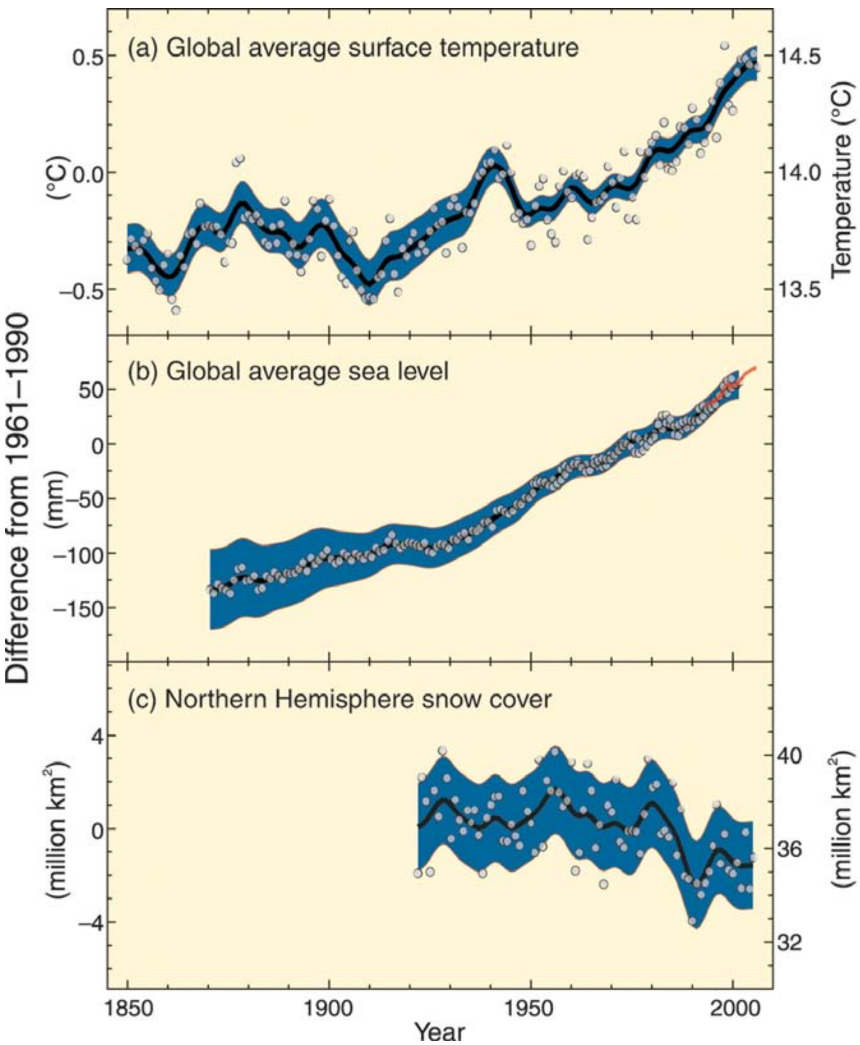


Figure 1. Observed changes in (a) global average surface temperature; (b) global average sea level from tide gauge (blue) and satellite (red) data and (c) Northern Hemisphere snow cover for March-April. All differences are relative to corresponding averages for the period 1961-1990. Smoothed curves represent decadal averaged values while circles show yearly values. The shaded areas are the uncertainty intervals estimated from a comprehensive analysis of known uncertainties (a and b) and from the time series (c) (IPCC 2007a).

A. Temperature and Greenhouse Gases

What scientists know…

- Warming of the Earth's climate system is unequivocal, as evidenced from increased air and ocean temperatures, widespread melting of snow and ice, and rising global average sea level (Figure 1).

- In the last 100 years, global average surface temperature has risen about 0.74°C over the previous 100-year period, and the rate of warming has doubled from the previous century. Eleven of the 12 warmest years in the instrumental record of global surface temperature since 1850 have occurred since 1995 (Figure 1).

- Although most regions over the globe have experienced warming, there are regional variations: land regions have warmed faster than oceans and high northern latitudes have warmed faster than the tropics. Average Arctic temperatures have increased at almost twice the global rate in the past 100 years, primarily because loss of snow and ice results in a positive feedback via increased absorption of sunlight by ocean waters (Figure 2).

- Over the past 50 years widespread changes in extreme temperatures have been observed, including a decrease in cold days and nights and an increase in the frequency of hot days, hot nights, and heat waves.

- Winter temperatures are increasing more rapidly than summer temperatures, particularly in the northern hemisphere, and

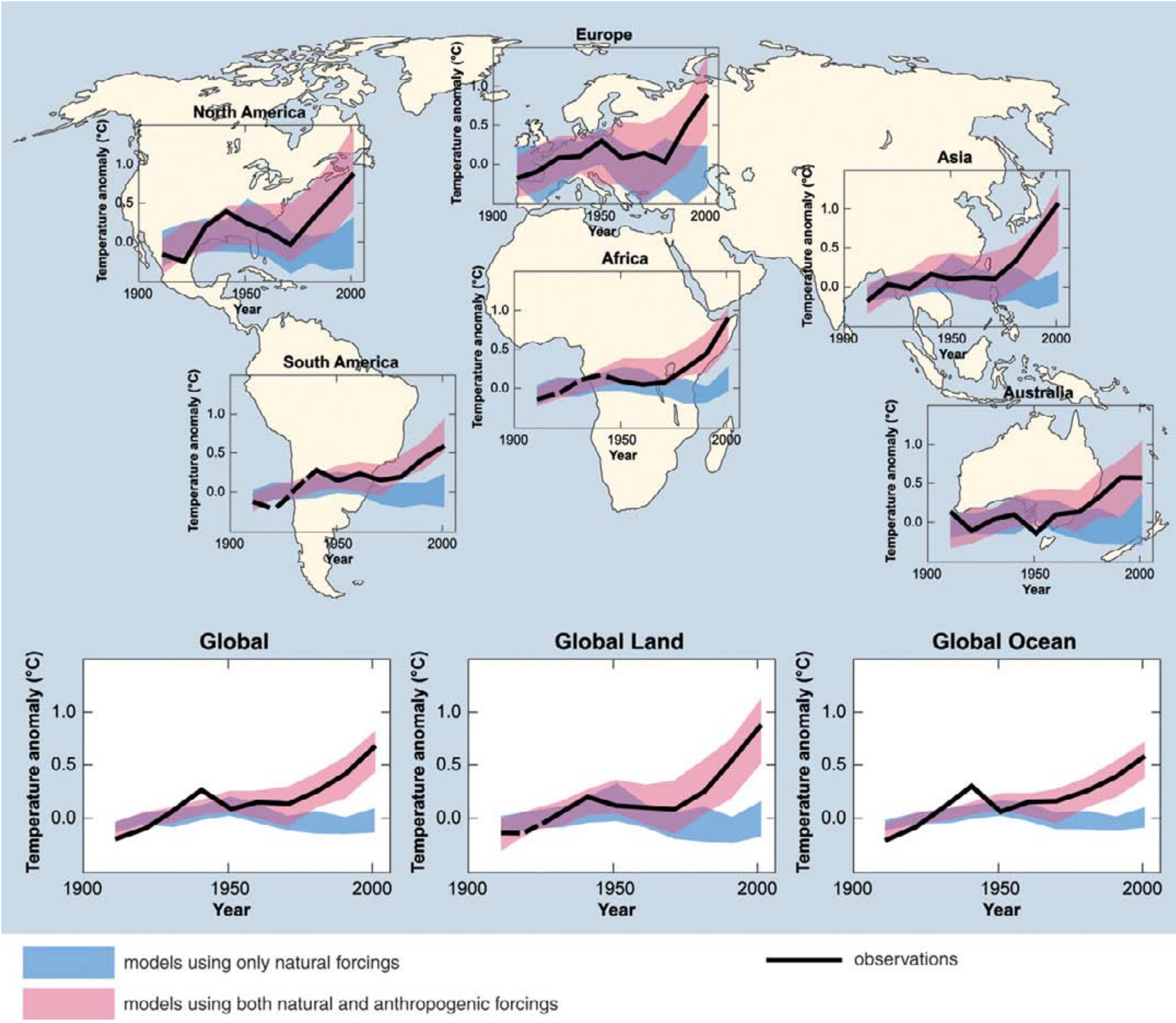


Figure 2. Comparison of observed continental- and global-scale changes in surface temperature with results simulated by climate models using either natural or both natural and anthropogenic forcings. Decadal averages of observations are shown for the period 1906-2005 (black line) plotted against the centre of the decade and relative to the corresponding average for the period 1901-1950. Lines are dashed where spatial coverage is less than 50%. Blue shaded bands show the 5 to 95% range for 19 simulations from five climate models using only the natural forcings due to solar activity and volcanoes. Red shaded bands show the 5 to 95% range for 58 simulations from 14 climate models using both natural and anthropogenic forcings (IPCC 2007a).

there has been an increase in the length of the frost-free period in mid- and high-latitude regions of both hemispheres.

- Climate change is caused by alterations in the energy balance within the atmosphere and at the Earth's surface. Factors that affect Earth's energy balance are the atmospheric concentrations of greenhouse gases and aerosols, land surface properties, and solar radiation.

- Global atmospheric concentrations of greenhouse gases have increased significantly since 1750 as the result of human activities. The principal greenhouse gases are carbon dioxide (CO_2), primarily from fossil fuel use and land-use change; methane (CH_4) and nitrous oxide (N_2O), primarily from agriculture; and halocarbons (a group of gases containing fluorine, chlorine or bromine), principally engineered chemicals that do not occur naturally.

- Direct measurements of gases trapped in ice cores demonstrate that current CO_2 and CH_4 concentrations far exceed the natural range over the last 650,000 years and have increased markedly (35% and 148% respectively), since the beginning of the industrial era in 1750.

- Both past and future anthropogenic CO_2 emissions will continue to contribute to warming and sea level rise for more than a millennium, due to the time scales required for the removal of the gas from the atmosphere.

- Warming temperatures reduce oceanic uptake of atmospheric CO_2, increasing the fraction of anthropogenic emissions remaining in the atmosphere. This positive carbon cycle feedback results in increasingly greater accumulation of atmospheric CO_2 and subsequently greater warming trends than would otherwise be present in the absence of a feedback relationship.

- There is very high confidence that the global average net effect of human activities since 1750 has been one of warming.

- Scientific evidence shows that major and widespread climate changes have occurred with startling speed. For example, roughly half the north Atlantic warming during the last 20,000 years was achieved in only a decade, and it was accompanied by significant climatic changes across most of the globe (NRC 2008).

What scientists think is likely…

- Anthropogenic warming over the last three decades has likely had a discernible influence at the global scale on observed changes in many physical and biological systems.

- Average temperatures in the Northern Hemisphere during the second half of the 20th century were very likely higher than during any other 50-year period in the last 500 years and likely the highest in at least the past 1300 years.

- Most of the warming that has occurred since the mid-20th century is very likely due to increases in anthropogenic greenhouse gas concentrations. Furthermore, it is extremely likely that global changes observed in the past 50 years can only be explained with external (anthropogenic) forcings (Figure 2).

- There is much evidence and scientific consensus that greenhouse gas emissions will continue to grow under current climate change mitigation policies and development practices. For the next two decades a warming of about 0.2°C per decade is projected for a range of emissions scenarios; afterwards, temperature projections increasingly depend on specific emissions scenarios (Table 1).

- It is very likely that continued greenhouse gas emissions at or above the current rate will cause further warming and result in changes in the global climate system that will be larger than those observed during the 20th century.

- It is very likely that hot extremes, heat waves and heavy precipitation events will become more frequent. As with current trends, warming is expected to be greatest over land and at most high northern latitudes, and least over the Southern Ocean (near Antarctica) and the northern North Atlantic Ocean.

What scientists think is possible…

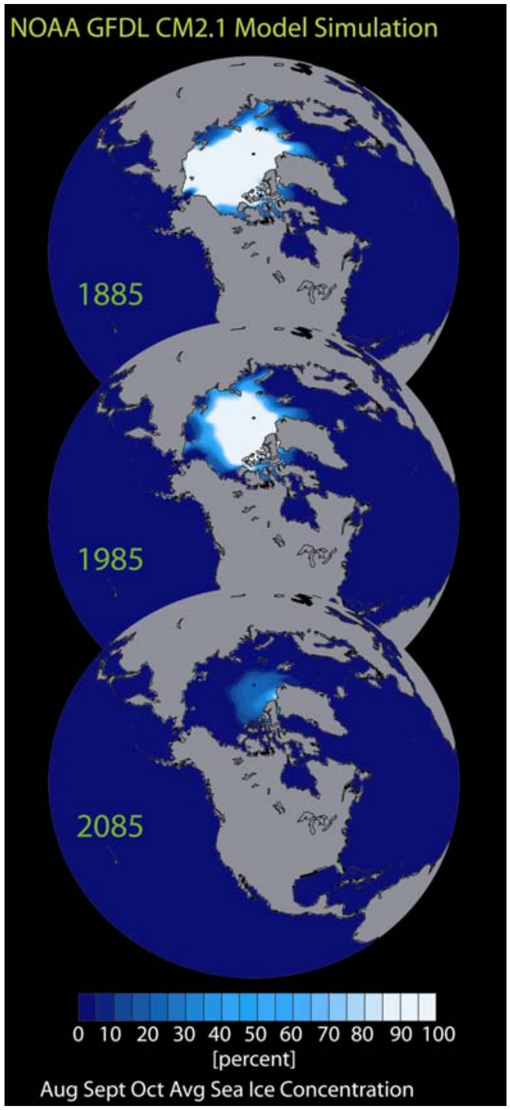
- Global temperatures are projected to increase in the future, and the magnitude of temperature change depends on specific emissions scenarios, and ranges from a 1.1°C to 6.4°C increase by 2100 (Table 1).

Table 1. Projected global average surface warming at the end of the 21st century, adapted from (IPCC 2007b).

Notes: a) Temperatures are assessed best estimates and likely uncertainty ranges from a hierarchy of models of varying complexity as well as observational constraints. b) Temperature changes are expressed as the difference from the period 1980-1999. To express the change relative to the period 1850-1899 add 0.5°C. c) Year 2000 constant composition is derived from Atmosphere-Ocean General Circulation Models (AOGCMs) only.

	Temperature Change (°C at 2090 – 2099 relative to 1980 – 1999)[a,b]	
Emissions Scenario	**Best Estimate**	**Likely Range**
Constant Year 2000 Concentrations[a]	0.6	0.3 – 0.9
B_1 Scenario	1.8	1.1 – 2.9
B_2 Scenario	2.4	1.4 – 3.8
A_1B Scenario	2.8	1.7 – 4.4
A_2 Scenario	3.4	2.0 – 5.4
A_1F_1 Scenario	4.0	2.4 – 6.4

Figure 3. Sea ice concentrations (the amount of ice in a given area) simulated by the GFDL CM2.1 global coupled climate model averaged over August, September and October (the months when Arctic sea ice concentrations generally are at a minimum). Three years (1885, 1985 & 2085) are shown to illustrate the model-simulated trend. A dramatic reduction of summertime sea ice is projected, with the rate of decrease being greatest during the 21st century portion. The colors range from dark blue (ice free) to white (100% sea ice covered); Image courtesy of NOAA GFDL.



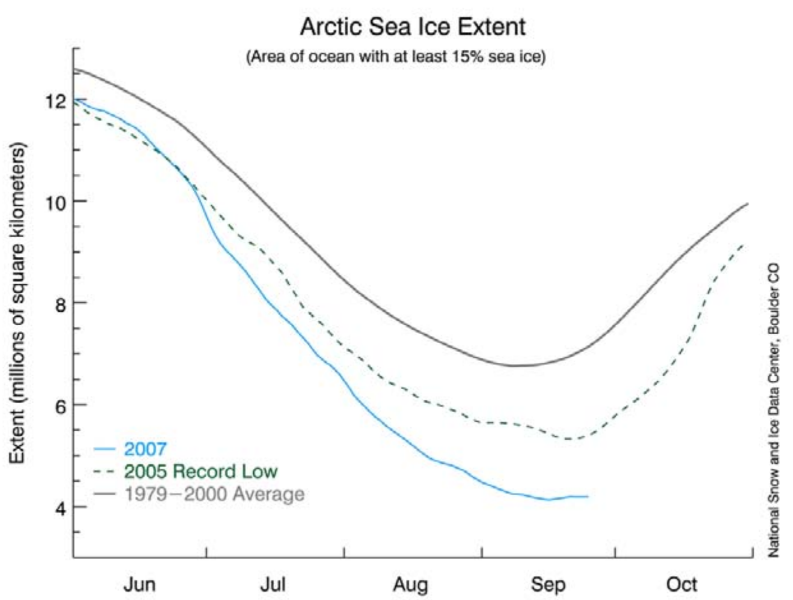


Figure 4. Arctic sea ice in September 2007 (blue line) is far below the previous low record year of 2005 (dashed line), and was 39% below where we would expect to be in an average year (solid gray line). Average September sea ice extent from 1979 to 2000 was 7.04 million square kilometers. The climatological minimum from 1979 to 2000 was 6.74 million square kilometers (NSIDC 2008).

- Anthropogenic warming could lead to changes in the global system that are abrupt and irreversible, depending on the rate and magnitude of climate change.

- Roughly 20-30% of species around the globe could become extinct if global average temperatures increase by 2 to 3°C over pre-industrial levels.

B. Water, Snow, and Ice

What scientists know…

- Many natural systems are already being affected by increased temperatures, particularly those related to snow, ice, and frozen ground. Examples are decreases in snow and ice extent, especially of mountain glaciers; enlargement and increased numbers of glacial lakes; decreased permafrost extent; increasing ground instability in permafrost regions and rock avalanches in mountain regions; and thinner sea ice and shorter freezing seasons of lake and river ice (Figure 3).

- Annual average Arctic sea ice extent has shrunk by 2.7% per decade since 1978, and the summer ice extent has decreased by 7.4% per decade. Sea ice extent during the 2007 melt season plummeted to the lowest levels since satellite measurements began in 1979, and at the end of the melt season September 2007 sea ice was 39% below the long-term (1979-2000) average (NSIDC 2008)(Figure 4).

- Global average sea level rose at an average rate of 1.8 mm per year from 1961 to 2003 and at an average rate of 3.1 mm per year from 1993 to 2003. Increases in sea level since 1993 are the result of the following contributions: thermal expansion, 57%; melting glaciers and ice caps, 28%, melting polar ice sheets, 15%.

- The CO_2 content of the oceans increased by 118 ± 19 Gt (1 Gt = 109 tons) between A.D. 1750 (the end of the pre-industrial period) and 1994 as the result of uptake of anthropogenic CO_2 emissions from the atmosphere, and continues to increase by about 2 Gt each year (Sabine et al. 2004; Hoegh-Guldberg et al. 2007). This increase in oceanic CO_2 has resulted in a 30% increase in acidity (a decrease in surface ocean pH by an average of 0.1 units), with observed and potential severe negative consequences for marine organisms and coral reef formations (Orr et al. 2005: McNeil and Matear 2007; Riebesell et al. 2009).

- Oceans are noisier due to ocean acidification reducing the ability of seawater to absorb low frequency sounds (noise from ship traffic and military activities). Low-frequency sound absorption has decreased over 10% in both the Pacific and Atlantic over the past 200 years. An assumed additional pH drop of 0.3 (due to anthropogenic CO_2 emissions) accompanied with warming will lead to sound absorption below 1 kHz being reduced by almost half of current values (Hester et. al. 2008).

- Even if greenhouse gas concentrations are stabilized at current levels thermal expansion of ocean waters (and resulting sea level rise) will continue for many centuries, due to the time required to transport heat into the deep ocean.

- Observations since 1961 show that the average global ocean temperature has increased to depths of at least 3000 meters, and that the ocean has been taking up over 80% of the heat added to the climate system.

- Hydrologic effects of climate change include increased runoff and earlier spring peak discharge in many glacier- and snow-fed rivers, and warming of lakes and rivers.

- Runoff is projected to increase by 10 to 40% by mid-century at higher latitudes and in some wet tropical areas, and to decrease by 10 to 30% over some dry regions at mid-latitudes and dry tropics. Areas in which runoff is projected to decline face a reduction in the value of the services provided by water resources.

- Precipitation increased significantly from 1900 to 2005 in eastern parts of North and South America, northern Europe, and northern and central Asia. Conversely, precipitation declined in the Sahel, the Mediterranean, southern Africa, and parts of southern Asia (Figure 5).

What scientists think is likely….

- Widespread mass losses from glaciers and reductions in snow cover are projected to accelerate throughout the 21st century, reducing water availability and changing seasonality of flow patterns.

- Model projections include contraction of snow cover area, widespread increases in depth to frost in permafrost areas, and Arctic and Antarctic sea ice shrinkage.

- The incidence of extreme high sea level has likely increased at a broad range of sites worldwide since 1975.

- Based on current model simulations it is very likely that the meridional overturning circulation (MOC) of the Atlantic Ocean will slow down during the 21st century; nevertheless regional temperatures are predicted to increase. Large-scale and persistent changes in the MOC may result in changes in marine ecosystem produc-

Figure 5. Relative changes in precipitation (in percent) for the period 2090-2099, relative to 1980-1999. Values are multi-model averages based on the SRES A_1B scenario for December to February (left) and June to August (right). White areas are where less than 66% of the models agree in the sign of the change and stippled areas are where more than 90% of the models agree in the sign of the change (IPCC 2007a).

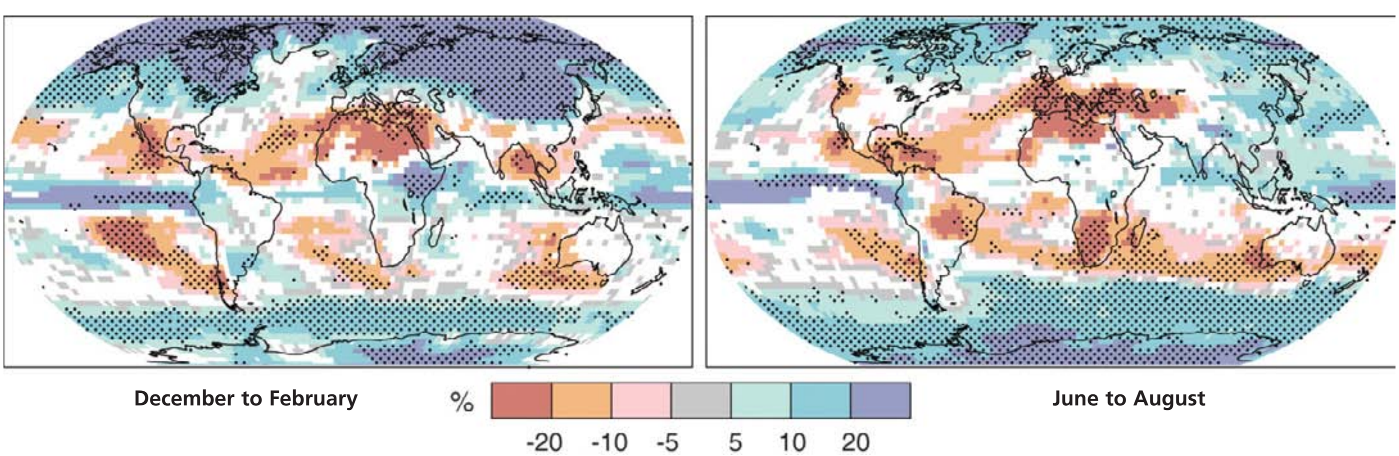


Table 2. Projected global average sea level rise at the end of the 21st century, adapted from IPCC 2007b.

Notes: a) Temperatures are assessed best estimates and likely uncertainty ranges from a hierarchy of models of varying complexity as well as observational constraints.

Emissions Scenario	Sea level rise (m at 2090 – 2099 relative to 1980 – 1999)
	Model-based range (excluding future rapid dynamical changes in ice flow)
Constant Year 2000 Concentrations[a]	0.3 – 0.9
B_1 Scenario	1.1 – 2.9
B_2 Scenario	1.4 – 3.8
A_1B Scenario	1.7 – 4.4
A_2 Scenario	2.0 – 5.4
A_1F_1 Scenario	2.4 – 6.4

tivity, fisheries, ocean CO2 uptake, and terrestrial vegetation.

- Globally the area affected by drought has likely increased since the 1970s and the frequency of extreme precipitation events has increased over most areas.

- Future tropical cyclones (typhoons and hurricanes) are likely to become more intense, with larger peak wind speeds and increased heavy precipitation. Extra-tropical storm tracks are projected to move poleward, with consequent shifts in wind, precipitation, and temperature patterns.

- Increases in the amount of precipitation are very likely in high latitudes and decreases are likely in most subtropical land regions, continuing observed patterns (Figure 5).

- Increases in the frequency of heavy precipitation events in the coming century are very likely, resulting in potential damage to crops and property, soil erosion, surface and groundwater contamination, and increased risk of human death and injury.

What scientists think is possible…

- Arctic late-summer sea ice may disappear almost entirely by the end of the 21st century (Figure 3).

- Current global model studies project that the Antarctic ice sheet will remain too cold for widespread surface melting and gain mass due to increased snowfall. However, net loss of ice mass could occur if dynamical ice discharge dominates the ice sheet mass balance.

- Model-based projections of global average sea level rise at the end of the 21st century range from 0.18 to 0.59 meters, depending on specific emissions scenarios (Table 2). These projections may actually underestimate future sea level rise because they do not include potential feedbacks or full effects of changes in ice sheet flow.

- Partial loss of ice sheets and/or the thermal expansion of seawater over very long time scales could result in meters of sea level rise, major changes in coastlines and inundation of low-lying areas, with greatest effects in river deltas and low-lying islands.

C. Vegetation and Wildlife

What scientists know…

- Temperature increases have affected Arctic and Antarctic ecosystems and predator species at high levels of the food web.

- Changes in water temperature, salinity, oxygen levels, circulation, and ice cover in marine and freshwater ecosystems have resulted in shifts in ranges and changes in algal, plankton, and fish abundance in high-latitude oceans; increases in algal and zooplankton abundance in high-latitude and high-altitude lakes; and range shifts and earlier fish migrations in rivers.

- High-latitude (cooler) ocean waters are currently acidified enough to start dissolving pteropods; open water marine snails which are one of the primary food sources of young salmon and mackerel (Fabry et al. 2008, Feely et al. 2008). In lower latitude (warmer) waters, by the end of this century Humboldt squid's metabolic rate will be reduced by 31% and activity levels by 45% due to reduced pH, leading to squid retreating at night to shallower waters to feed and replenish oxygen levels (Rosa and Seibel 2008).

- A meta-analysis of climate change effects on range boundaries in Northern Hemisphere species of birds, butterflies, and alpine herbs shows an average shift of 6.1 kilometers per decade northward (or 6.1 meters per decade upward), and a mean shift toward earlier onset of spring events (frog breeding, bird nesting, first flowering, tree budburst, and arrival of migrant butterflies and birds) of 2.3 days per decade (Parmesan and Yohe 2003).

- Poleward range shifts of individual species and expansions of warm-adapted communities have been documented on all continents and in most of the major oceans of the world (Parmesan 2006).

- Satellite observations since 1980 indicate a trend in many regions toward earlier greening of vegetation in the spring linked to longer thermal growing seasons resulting from recent warming.

- Over the past 50 years humans have changed ecosystems more rapidly and extensively than in any previous period of human history, primarily as the result of growing demands for food, fresh water, timber, fiber, and fuel. This has resulted in a substantial and largely irreversible loss of Earth's biodiversity

- Although the relationships have not been quantified, it is known that loss of intact ecosystems results in a reduction in ecosystem services (clean water, carbon sequestration, waste decomposition, crop pollination, etc.).

What scientists think is likely…

- The resilience of many ecosystems is likely to be exceeded this century by an unprecedented combination of climate change, associated disturbance (flooding, drought, wildfire, insects, ocean acidification) and other global change drivers (land use change, pollution, habitat fragmentation, invasive species, resource over-exploitation) (Figure 6).

- Exceedance of ecosystem resilience may be characterized by threshold-type responses such as extinctions, disruption of ecological interactions, and major changes in ecosystem structure and disturbance regimes.

- Net carbon uptake by terrestrial ecosystems is likely to peak before mid-century and then weaken or reverse, amplifying climate changes. By 2100 the terrestrial biosphere is likely to become a carbon source.

- Increases in global average temperature above 1.5 to 2.5°C and concurrent atmospheric CO_2 concentrations are projected to result in major changes in ecosystem structure and function, species' ecological interactions, and species' geographical ranges. Negative consequences are projected for species biodiversity and ecosystem goods and services.

- Model projections for increased atmospheric CO_2 concentration and global temperatures significantly exceed values for at least the past 420,000 years, the period during which more extant marine organisms evolved. Under expected 21st century conditions it is likely that global warming and ocean acidification will compromise carbonate accretion, resulting in less diverse reef communities and failure of some existing carbonate reef structures. Climate changes will likely exacerbate local stresses from declining water quality and overexploitation of key species (Hoegh-Guldberg et al. 2007).

- Ecosystems likely to be significantly impacted by changing climatic conditions include:

  i. Terrestrial – tundra, boreal forest, and mountain regions (sensitivity to warming); Mediterranean-type ecosystems and tropical rainforests (decreased rainfall)

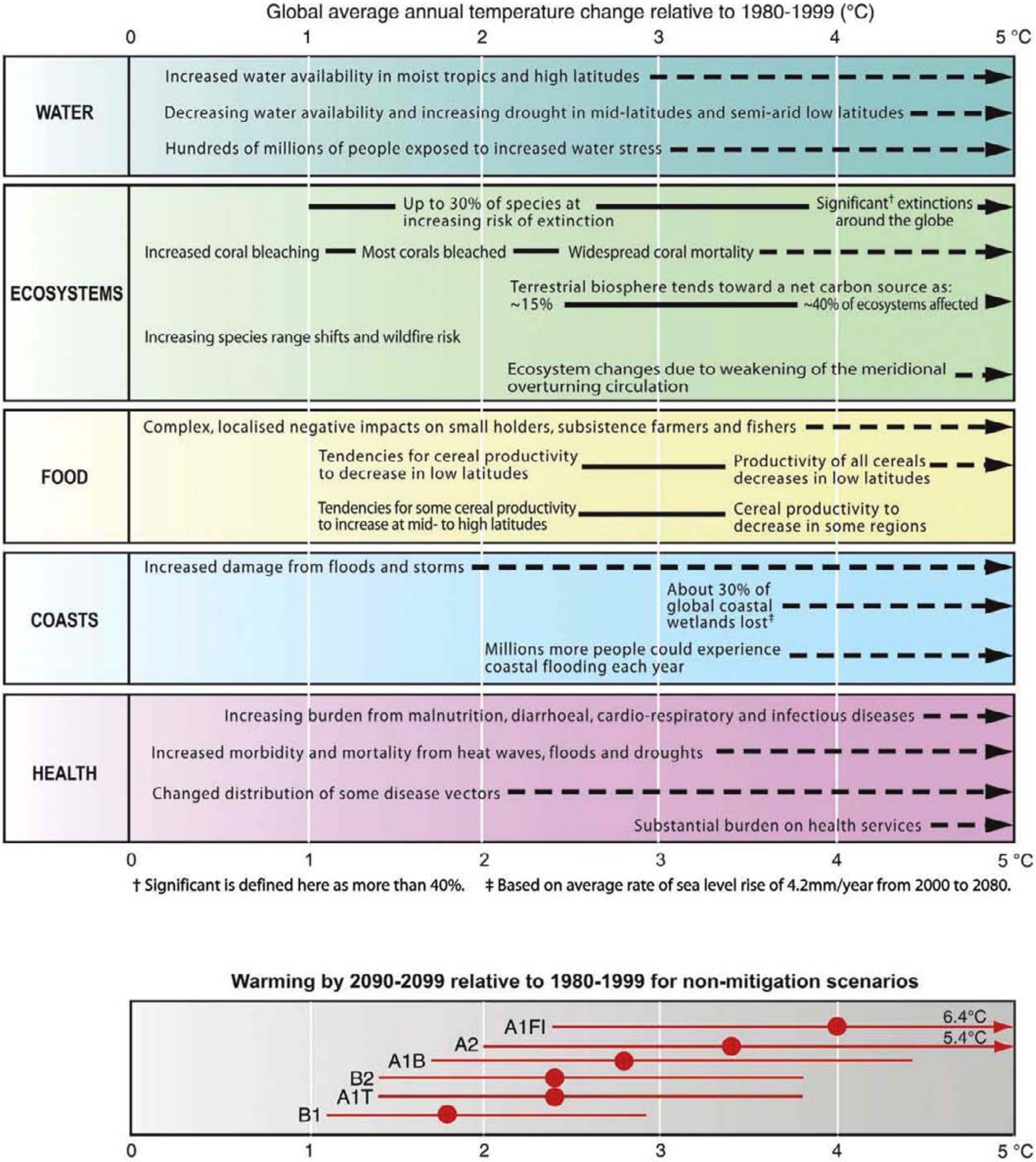


Figure 6. Examples of impacts associated with projected global average surface warming. Upper panel: Illustrative examples of global impacts projected for climate changes (and sea level and atmospheric CO_2 where relevant) associated with different amounts of increase in global average surface temperature in the 21st century. The black lines link impacts; broken-line arrows indicate impacts continuing with increasing temperature. Entries are placed so that the left-hand side of text indicates the approximate level of warming that is associated with the onset of a given impact. Quantitative entries for water scarcity and flooding represent the additional impacts of climate change relative to the conditions projected across the range of SRES scenarios A1FI, A2, B1 and B2. Adaptation to climate change is not included in these estimations. Confidence levels for all statements are high. Lower panel: Dots and bars indicate the best estimate and likely ranges of warming assessed for the six SRES marker scenarios for 2090-2099 relative to 1980-1999 (IPCC 2007a).

ii. Coastal – mangroves and salt marshes (multiple stresses)

iii. Marine – coral reefs (multiple stresses); sea-ice biomes (sensitivity to warming)

What scientists think is possible…

- Approximately 20% to 30% of plant and animal species assessed to date are at increased risk of extinction with increases in global average temperature in excess of 1.5 to 2.5°C.

- Endemic species may be more vulnerable to climate changes, and therefore at higher risk for extinction, because they may have evolved in locations where paleo-climatic conditions have been stable.

- Although there is great uncertainty about how forests will respond to changing climate and increasing levels of atmospheric CO_2, the factors that are most typically predicted to influence forests are increased fire, increased drought, and greater vulnerability to insects and disease (Brown 2008).

- If atmospheric CO_2 levels reach 450 ppm (projected to occur by 2030–2040 at the current emissions rates), reefs may experience rapid and terminal decline worldwide from multiple climate change-related direct and indirect effects including mass bleaching, ocean acidification, damage to shallow reef communities,reduction of biodiversity, and extinctions. (Veron et al. 2009). At atmospheric CO_2 levels of 560 ppmv, calcification of tropical corals is expected to decline by 30%, and loss of coral structure in areas of high erosion may outpace coral growth. With unabated CO_2 emissions, 70% of the presently known reef locations (including cold-water corals) will be in corrosive waters by the end of this century (Riebesell, et al. 2009).

D. Disturbance

What scientists know…

- Climate change currently contributes to the global burden of disease and premature death through exposure to extreme events and changes in water and air quality, food quality and quantity, ecosystems, agriculture, and economy (Parry et al. 2007).

- The most vulnerable industries, settlements, and societies are generally those in coastal and river flood plains, those whose economies are closely linked with climate-sensitive resources, and those in areas prone to extreme weather events.

- By 2080-2090 millions more people than today are projected to experience flooding due to sea level rise, especially those in the low-lying megadeltas of Asia and Africa and on small islands.

- Climate change affects the function and operation of existing water infrastructure and water management practices, aggravating the impacts of population growth, changing economic activity, land-use change, and urbanization.

What scientists think is likely…

- Up to 20% of the world's population will live in areas where river flood potential could increase by 2080-2090, with major consequences for human health, physical infrastructure, water quality, and resource availability.

- The health status of millions of people is projected to be affected by climate change, through increases in malnutrition; increased deaths, disease, and injury due to extreme weather events; increased burden of diarrheal diseases; increased cardio-respiratory disease due to higher concentrations of ground-level ozone in urban areas; and altered spatial distribution of vector-borne diseases.

- Risk of hunger is projected to increase at lower latitudes, especially in seasonally dry and tropical regions.

What scientists think is possible…

- Although many diseases are projected to increase in scope and incidence as the result of climate changes, lack of appropriate longitudinal data on climate change-related health impacts precludes definitive assessment.

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